PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

IN SIX CHAPTERS.

BY HUGH SMITH, M. D.

Of HATTON-STREET.

With a View to ſhew the Probability of AIR being the firſt CAUSE of MOTION in ANIMAL LIFE; to point out the MECHANICAL CAUSES that concur in producing the CIRCULATION of the BLOOD; and to explain the LAWS of RESPIRATION.

Theſe Inquiries are ſupported by Experiments, and founded on the Principles delivered in a Courſe of PHILOSOPHICAL LECTURES, in the Beginning of the YEAR 1778.

The Principles are ſet forth in the Author's SYLLABUS.

LONDON:

Printed for L. Davis, Holborn; J. Robſon, New Bond-Street; J. Dodſley, Pall-Mall; T. Cadell, Strand; G. Kearſly, Fleet-Street; G. Robinſon, and T. Evans, Paternoſter-Row; and Meſſrs. Richardſon and Urquhart, Royal-Exchange.

M DCC LXXX.

☞ *The Work is printed in Quarto for the Convenience of thoſe who chuſe to have it bound with the* SYLLABUS.

The Second Chapter will be publiſhed the Beginning of April.

PHILOSOPHICAL INQUIRIES

INTO THE

LAWS of ANIMAL LIFE

TO

WILLIAM HUNTER, M. D.

ANATOMICAL PROFESSOR in LONDON, F. R. S.
And PHYSICIAN EXTRAORDINARY to the QUEEN.

TO you, Sir, this firſt chapter of my Inquiries is moſt gratefully inſcribed, becauſe from you I received thoſe Rudiments of Science, which enabled me, among my other philoſophical attempts, to purſue the ſtudy of Human Nature.

PERMIT me, Sir, to congratulate you that London is now become the great School of Phyſic: your unremitting labours in this Metropolis, towards the improvement of medical knowledge, are ſo univerſally known, that the world need not be told, by me, of your ſuperior merit; a conſideration which renders it no eaſy taſk to find words that may not offend, even in paying this humble tribute of gratitude.

ALL, therefore, I have to hope for, is, that you will condeſcend to regard my bold attempt with your uſual goodneſs; and, that you will be pleaſed to pardon my errors: from you, Sir, I am encouraged to look for theſe indulgencies, for I know that you poſſeſs a mind as liberal by Nature, as it is enlarged by Science.

MAY you long continue to enjoy your public honours, as well as thoſe private rewards which ever accompany virtue!

I am, Sir, with reſpect and eſteem,

Your moſt obedient, and moſt humble Servant,

HUGH SMITH.

Hatton-Street, London,
Feb. 25, 1780.

PREFACE.

IN the courſe of Lectures delivered the beginning of the year 1778, on the Philoſophy of Phyſic, which may juſtly be called the ſtudy of Nature, this was laid down as the leading aphoriſm: *In all living animals, life, heat, and motion, are inſeparable.* To prove this point, I began with conſidering Air as matter, and by progreſſive ſteps advanced to the 34th and laſt principle, which runs thus—VITAL AIR, *heat and motion, appear to be inſeparable in animal life.* It is therefore meant to be inſiſted on, that Air is the firſt material cauſe of every motion proper to life.

An Operator attended every night to exhibit the experiments on which my arguments were founded; and the principles have now been ſubmitted to the Public near two years, with an earneſt hope on my own part, that any fallacies in them might be detected: the principles, however, at preſent remain uncontroverted.

It was thought neceſſary, in the firſt inſtance, to eſtabliſh the proofs by experiments; which are for the moſt part familiar, and none of them repugnant to the known laws of Pneumatics: learned and philoſophic men, therefore, may receive ſufficient information from my Syllabus alone; on which account it appears unneceſſary to repeat the lectures, and my profeſſional engagements, at this time, would render it very inconvenient to myſelf. If the principles be admitted, it is all I aſk; for the purpoſe of the Lectures is thereby fully anſwered; and we may, with propriety, purſue the following inquiries—Should the preſent attempt merit approbation, the Lectures themſelves may, perhaps, hereafter be found an uſeful introduction to this branch of natural philoſophy; in that caſe they will be at the ſervice

of

of the Public.—This, I truſt, will be received as a general and ſatisfactory anſwer, to the many and reſpectable applications made to me to deliver another courſe of lectures: beſides, the ſubject is too important to be haſtily purſued, and it is my ſincere deſire, that the preſent thoughts ſhould be moſt ſtrictly examined; I hope, therefore, theſe apologies will be received with candour.

It would have been preſumption in me, to have ſtyled many of the opinions formerly delivered, more than conjectures: whether or not any of them deſerve an higher name, the Public will determine from the preſent application of them. Some profeſſional men have been pleaſed to call them ingenious; it is my wiſh more particularly to claim their attention to this publication. Theſe opinions, if they be, as I hope, found true, muſt overturn many doctrines now taught, and bid fair to eſtabliſh rational theories, founded on experimental philoſophy, concerning ſome of the moſt obſtinate diſeaſes.

To regulate phyſiological reaſonings throughout the animal œconomy, on new principles, will prove, indeed, an arduous purſuit: if, however, what is here laid down ſhould be found uſeful, my induſtry ſhall not be wanting to chalk out ſome rude outlines of their extenſive application, which may, at a future period, be more completely filled up by abler men, whereby mankind may be eſſentially benefited—which is the ultimate wiſh of the author.

PHILOSOPHICAL INQUIRIES
INTO THE
LAWS OF ANIMAL LIFE.

CHAPTER THE FIRST.

CONTENTS.

Vital Air the firſt material cauſe of motion in Animal Life: Pulſation deſcribed: Animal blood a mere paſſive fluid—the common menſtruum *of Nutrition only: the Harveyan and Boerhaavean theories, concerning the circulation of the blood, ſet forth, with the author's objections.*

IN the courſe of our lectures we entered pretty fully into the ſubject of animal life; but as the lectures are not publiſhed it may be proper to ſpeak a little to this point, before we conſider that mechanical power by which the blood is kept in perpetual motion through the animal œconomy.

When our great countryman found out, and demonſtrated by experiments, the circulation of the blood, for this important diſcovery he was ſtyled the immortal Harvey; and ſhould he be wrong in ſome of the cauſes aſſigned for this wonderful effect, the merit of the diſcovery is ſtill the ſame, as he thereby paved the way for farther inquiries: let us then pay the juſt tribute of praiſe to the memory of ſo illuſtrious a character, and modeſtly endeavour to trace out the points wherein he, as well as other great men have been miſtaken. It is proper to remark, that throughout the whole of our Inquiries material cauſes *only* have been the objects of purſuit; and that all our reaſonings have been ſupported by experiments.

When it pleaſed the Almighty to put matter into Motion, we cannot doubt but general laws were ordained, by his moſt gracious Providence, to ſupport the Works of his Creation: ſome of thoſe laws, then, reſpecting Animal Life, we are at this time attempting to diſcover.

The proper ſtandard of Vital Air having been fixed by the Author of Nature when he firſt created Man, we hope to ſhew that ſtandard is regularly and uniformly maintained by means of the atmoſpheric air; and that the continuation of life does not depend on any myſterious, or unknown principle exiſting in the brain, in the nervous ſyſtem, or in the blood only; but on the conſtant admiſſion of the common

air

air of the atmoſphere into the animal œconomy, which keeps the blood, and all the other humours of an animal body, in perpetual motion: for under the ſame circumſtances of heat, and cloſe confinement in tubes, we have ſhewn by experiments, a ſimilar effect may be produced by air on other fluids, cauſing them to circulate in like manner as the blood itſelf.

We regard Air, rarified by heat, as the firſt material cauſe of motion in Animal Life; and the re-action of the vaſcular ſyſtem as the ſecondary cauſe. Theſe two cauſes, taken conjunctively, produce that complete motion, termed Pulſation; by which the blood is conveyed from the heart to the extreme parts of the arterial ſyſtem; and, if there be no re-action in the venal tubes, it is returned to the heart again by the power of Air.

We allowed the re-action of the vaſcular ſyſtem greatly to depend on the nerves, but endeavoured to ſhew that the nerves themſelves were primarily indebted to Vital Air for their power.

By the propelling force of Vital Air, we preſume all glandular ſecretions to be performed, for the purpoſe of Nutrition; and the lymphatic circulations to be ſupported by the ſame power: and alſo by means of the Glands, we preſume the laws of generation to be maintained.

THE Blood we conſider as an elaborated fluid, prepared within the body of every animal, by its own corporeal powers, from proper aliment received; from whence Nutrition is derived by means of the Glands. Even the Mother's milk neceſſarily undergoes a material change within the body of an Infant, before it contributes to nutrition.

ALL the various nutritive ſubſtances received into the ſtomach of an animal muſt be digeſted, and the particles of matter differently arranged, before the nutritive juices are capable of being received into the chyliferous veſſels, and conducted to the *vena cava* to mix and circulate with the blood.

THE nutritive juices received into the blood, in form of chyle, muſt undergo ſeveral other changes, before they actually become blood.

IN our lectures we conſidered the blood of an animal as the common *menſtruum* of Nutrition *only*; regarding it in the light of a mere paſſive fluid, kept in continual motion by the Air conſtantly admitted into it; and we endeavoured to prove Air to be its invigorating or firſt moving principle.

THE Hypotheſis of life exiſting in the blood certainly owes its origin to Moſes, though firſt adopted philoſophically by

by Dr. Harvey, who even goes ſo far as to ſuppoſe the blood to be the ſeat of the ſoul *.

To this point, in our introductory lecture we expreſſed ourſelves as follows:

We do not pretend to determine in what part the ſentient principle is ſeated in man; we know that man has a ſpirit or thinking principle exiſting in him, and with this knowledge let us reſt contented: for, if this ſpirit or thinking principle be immaterial, it cannot be an object of our ſenſes; and if it be not an object of our ſenſes, man's reſearches after it will ever prove in vain.

We ventured at the concluſion of the lectures to obſerve, that if there be a connection between groſs material, and immaterial ſubſtances, as it muſt be effected by means of

* It is not, however, probable that Moſes had any reference to immaterial cauſes at a time he was ſpeaking to the people concerning their daily food. "Every moving thing, "*ſays he*, that liveth, ſhall be meat for you, but fleſh with the life thereof, which is the "blood thereof, ſhall ye not eat." Gen. chap. ix.——

This appears to be nothing more than a forcible expreſſion to convey fully the meaning of the Lawgiver; for if the blood of an animal be taken away it ſurely dies; and hence Blood is familiarly ſtyled the fountain of life. It is not unlikely that Moſes might command the Jews to bleed the animals they were to feed upon, with a view to prevent the fleſh becoming too ſoon putrid; or perhaps to reſtrain them from brutiſh ferocity, and, (making a diſtinction between man and other animals) to add force to another law given in the ſame chapter: "Whoſo ſheddeth man's blood, by man alſo ſhall his blood be ſhed."

ſomething intermediate, this union was not unlikely to be formed by ſome *rare* medium; and if ſo, we aſked, why not by means of that Vital Air by which matter was firſt animated? And here we dropped the ſubject; our inquiries being altogether confined to material cauſes.

Dr. Harvey ſeems to have wanted nothing but the principle of Vital Air to have enabled him to complete his theory, without having recourſe to imaginary or unknown cauſes—Theſe are his words almoſt literally:

" Hence alſo appears the pre-eminence of the blood, that " pulſation derives its original from it: for as pulſation " conſiſts of two parts, namely diſtenſion and contraction, " or diaſtole and ſyſtole; and of theſe two motions the " diſtenſion is firſt; it is evident the former depends on the " blood, but the contraction is performed by the beating " veſicle in the egg (as by the heart in the chick) by means " of their proper fibres *."

Nothing can be more clear than this deſcription. Dr. Harvey ſpeaks to the very facts I ſhall have occaſion to con-

* Hinc quoque apparet ſanguinis principalitas, quod pulſus ex eo ortum ducat. Cum enim duæ ſint pulſationis partes, diſtenſio nempe et contractio, ſive diaſtole et ſyſtole, horumque motuum diſtenſio prior ſit; manifeſtum eſt actionem illam ſanguini competere: conſtrictionem vero, a veſicula pulſante in ovo (ut a corde in pullo) propriis fibris inſtitui—

Vide Harv. de generat. Animal. exercitat. 51.

tend

tend for, but not being acquainted with our principles, he could not make that uſe of experiments, which I am about to do.

THIS is evident from what follows; for he adds—" Nor " is the blood to be called an original and principal part, " only, becauſe in it, and from it, motion and the beginning " of pulſation ariſe; but alſo becauſe in it, animal heat " firſt is bred, *the vital ſpirit* is produced, and *the ſoul* itſelf " reſides *."

WHAT a fine mode of reaſoning! May I be permitted to ſay, how elegantly ingenious is this hypotheſis? How infinitely near does he approach, and yet does not ſeem to have the moſt diſtant conception, that Air was the unknown principle yet wanting, to produce all thoſe wonderful phenomena, that thus claimed his moſt curious attention? and which I hope to be able ſatisfactorily to explain.

I CANNOT help conſidering this great man as my valuable and good Ally, but we have a formidable Opponent to contend with—one who has endeavoured to overturn the whole of Dr. Harvey's theory, in order to eſtabliſh his own;

* Nec ſanguis ſolum pars primigenia et principalis dicendus eſt, quod in eo et ab eo motus pulſuſque principium oriatur; ſed etiam, quia in eo primum calor animalis innaſcitur, ſpiritus vitalis ingeneratur, et anima ipſa conſiſtit.

Ibid.

I mean

I mean the celebrated Boerhaave, who abſolutely affirms, "that the cauſe impelling the blood from the heart into the "arteries, and from the veins into the heart, is NOT in the "blood, but is to be ſought for in the heart itſelf." * He afterwards endeavours to prove the motion of the heart to be from the nerves; and to ſhew the brain, or rather a particular part of it, not the Pineal Gland as Des Cartes imagined, to be the ſeat of the ſoul †.

IN purſuit of his own ſyſtem, Boerhaave was reduced to the neceſſity of accounting for the ſyſtole prior to the diaſtole, contrary to the order of Nature ‡; which has led him and his followers into many difficulties; notwithſtanding which, his hypotheſis has obtained the preference over Dr. Harvey's; and is at preſent generally received; though I think I have been informed, that one of our anatomical profeſſors in this Metropolis has lately mentioned the Harveyan doctrine with reſpect.

FROM our obſervations perhaps it will appear that the re-action of the veſſels, which Boerhaave and his followers

* Cauſa igitur pellens ſanguinem ex corde in arterias, ex venis in cor, non eſt in ipſâ mole ſanguinis: ſed quærenda in eo, quod ſanguinem cordis proxime complectitur, id eſt, *in corde ipſo*.

Vide Inſtit. Boerh. 180, 181.

† Vide Inſtit. No. 574.

‡ Vide Inſtit. No. 189, 190.

make

make the firſt cauſe, is in reality only the ſecondary cauſe of the circulation; and that Dr. Harvey was altogether right in making the diaſtole precede the ſyſtole.

It will not, however, be unpleaſing to the learned, if we ſhould eventually ſhew, that both theſe great men, though totally oppoſite in their theories concerning the circulation, were neither of them far from the truth. One diſcovered motion firſt in the blood, but knew not the cauſe; the other diſcovered motion in the vaſcular ſyſtem, and miſtook it for the firſt cauſe: thus each of them ſaw in part, what I am about to relate; and both had recourſe to invention to ſupply what they did not ſee: hence, both of them were obliged to introduce imaginary agents.

Had our new experiments concerning Air been as well known to either of them as they are at this time to many gentlemen, moſt probably the honour of attempting to explain the laws of the circulation of Animal Fluids would not have fallen to my lot.

We ſhall now proceed to our inquiries, without animadverting on that ſyſtem which maintains the ſentient principle in man to be altogether material; that ſays it depends on, and is derived from, a ſyſtem of organiſed matter—This dangerous hypotheſis is evidently built on the Boerhaavean foundation, and if it ſhould appear that Boerhaave himſelf

has been miſtaken in regard to the nervous ſyſtem, his own fabric will neceſſarily be demoliſhed; and of courſe, it muſt follow, that this more modern ſuperſtructure will be buried with it in the ruins.

THE heart of an animal, in the courſe of our lectures, we ventured to ſtyle the centre of motion, reſpecting animal life.

ANATOMISTS deſcribe the heart to be a compound muſcle, compoſed of fibres of the ſame nature as thoſe of other muſcles: the heart has been conſidered to have two motions, termed ſyſtole and diaſtole.

THE motions of the heart are thus deſcribed: its ſyſtole, ſay they, is when the fibres of the heart contract, its ſides ſwell, and its cavities are diminiſhed, being ſtrongly preſſed on all ſides. The diaſtole is when this muſcle ceaſeth to act; its fibres being then lengthened, its ſides fall, and its cavities become large and wide: it is alſo particularly noted that the blood is expelled from the heart in the ſyſtole, and received into it, in its diaſtole; and the circulation of the blood, according to Boerhaave, whoſe opinion is almoſt univerſally embraced, is principally performed by the great power he aſcribes to this muſcle; which, however, Anatomiſts have proved to have no antagoniſts.

A DOCTRINE

A DOCTRINE ſo generally eſtabliſhed will not eaſily be overturned; this difficulty I am prepared to meet, as the prejudices of weak minds will not diſconcert me—for I conſider myſelf addreſſing liberal and ſcientific men at large, on a pleaſing branch of natural philoſophy; and we can boaſt of characters in the profeſſion who will pay reſpect to truth, though it may approach them in a rude and humble garb: however, the ſubject itſelf is by no means confined to medical men, although a rational practice of phyſic muſt ever be founded on the knowledge of the laws of Nature, reſpecting Animal Life.

THE mind muſt firſt doubt, before it will, in the leaſt, be diſpoſed to diſbelieve a doctrine, that has been eſtabliſhed for a ſeries of years; a doctrine that has overturned Dr. Harvey's theory, and which has been handed down to us through the reſpectable medium of learned authorities. As I cannot pretend to the power of perſuaſion, it would be in vain for me to attempt, in the firſt inſtance, to raiſe a doubt in the breaſt of any man; yet, perhaps, it may not be conſidered as time wholly miſpent, when I honeſtly relate that train of doubts and uncertainties that conducted me to the diſcovery of a contrary ſyſtem.

MANY years have paſſed ſince I firſt began to doubt the truth of the Boerhaavean theory concerning the circulation of the blood; and I doubted long, before thoſe doubts amounted

amounted to diſbelief; when diſbelief at length poſſeſſed my mind, it neceſſarily led me to endeavour to find out the ſallacy; and this inquiry could be purſued by no other means than an attempt to diſcover a cauſe, equal to the effect of keeping the blood, and other juices of the body, in their regular and conſtant motion; and to which cauſe I could more readily yield my rational aſſent.

My doubts aroſe on many points; and for the readers ſatisfaction, I ſhall mention a few: in the firſt place I could never conceive the muſcular force of the heart, conſidered independently, to be a power equal to the effect contended for; ſecondly, the heart being alternately dilated and contracted, and no antagoniſt muſcles being diſcovered, I could not ſuppoſe this two-fold operation to take place, without ſome other cauſe co-operating with the heart, and thereby ſupplying the place of antagoniſt muſcles. In the third place I conſidered the muſcles of the thorax, in the act of reſpiration, as they alſo are alternately dilated and contracted; and theſe muſcles being allowed to have no antagoniſts, the ſame difficulty preſented itſelf to account for their operation.

Thus my doubts encreaſed, and grew ſtronger; for theſe effects were aſcribed to cauſes I could not underſtand, and conſequently could not ſubſcribe to: that the heart ſtood in need of ſome co-operating power, to ſupply the place of antagoniſt muſcles ſeemed to be implied when animal

ſpirits

ſpirits were introduced into the ſyſtem of organiſed matter.

But when I read of animal ſpirits iſſuing from the nerves, and falling, drop by drop, into the muſcular fibres, to rarefy the blood, in order to explain muſcular motion, it was too myſterious for me to comprehend: being told that upon a drop of the animal ſpirits falling, the fibres are preſently inflated, and the muſcles contracted; and as ſoon as the rarefaction of the blood is over, the muſcle is relaxed till the next drop falls from the nerves; and that the ſyſtole and diaſtole of the heart are regularly produced by this wonderful contrivance, without the help of antagoniſt muſcles, or any other co-operating power; I could not help admiring the ingenuity of man, but doubted exceedingly whether he had yet diſcovered the wiſdom of the Author of Nature, in theſe mechanical operations of Animal Life.

It may not be improper to mention, that the moſt glaring abſurdity appeared to me to attend this theory, notwithſtanding it has been ſo generally admitted. The only idea I could ever affix to the term Animal Spirits is ſome fluid, containing ſo little matter that it might almoſt be ſtyled an immaterial principle; yet, poſſeſſed of much more power than air, or any other fluid, evidently material and perceptible:—if this may be called an idea, it is the one, I believe, uſually adopted by ſcientific men, when

the term Animal Spirits is made uſe of; and by them, this almoſt immaterial principle is appropriated to the moſt laborious material purpoſes, and univerſally ſpoken of as matter; it is on the preſent occaſion ſpecifically deſcribed as a fluid, with a property peculiar to fluids, of falling drop by drop:—ſuch ſeeming contradictions I could not reconcile.

ANOTHER palpable abſurdity, may I be permitted to ſay? attends this theory; for allowing the aid of animal ſpirits in the contracting power of the heart, the ſupporters of the Boerhaavean ſyſtem are reduced to the wretched dilemma of aſſerting the abſence of this power, or in other words the paſſive ſtate of this muſcle, to be the active cauſe of the diſtention of the heart; and when this difficulty is got over, take up the animal at what period of life you pleaſe, there muſt be ſuppoſed an exiſting power capable of bringing the blood, or nutritive juice, to the heart, before it can poſſibly be thrown out of it; ſo that what is termed the diaſtole muſt have exiſted before the ſyſtole could take place. This difficulty would have puzzled almoſt any other man than Boerhaave; but his ſurpriſing force of imagination overcame all impediments, and his ſuperior abilities enabled him to form new laws at pleaſure: his arguments alſo were delivered with ſuch a tone of weight as commanded the attention of his pupils, and they generally received his opinions

opinions without diſtruſt; of which the preſent is a notorious inſtance: and indeed moſt authors, ſince his time, have fallen into this moſt glaring error of placing the ſyſtole before the diaſtole; which, as before obſerved, is contrary to the order of Nature.

In purſuing this train of ideas, can it then be wondered at, that I ſhould be exceedingly averſe to the hypotheſis of animal ſpirits?

Being thus diſſatisfied with the preſent eſtabliſhed theory, I began to conſider ſome other muſcles which have no antagoniſts; for inſtance, the ſphincters of the *anus*, and the urinary bladder; which are not alternately relaxed, and contracted, like thoſe of the heart and thorax. In theſe exceptions I was equally diſſatisfied with the reaſons aſſigned—namely, that their force being very weak, their contraction was conſequently very ſmall, and differed ſo very little from their relaxation, as to be imperceptible to us: thus, the power of theſe muſcles ſeems to have been intentionally ſoftened down, ſo that the magic aid of animal ſpirits (which on theſe occaſions would have but little ſerved the cauſe) might appear to be leſs neceſſary.

This ſtrange doctrine I could not aſſent to, becauſe my own experience, by a little attention to my daily evacuations, convinced me of its fallacy: it not only ſatisfied

me

me the contracting power of theſe muſcles was very great on the occaſion of the expulſion of the evacuations; but I likewiſe diſcovered they afforded me voluntary power to reſiſt the evacuations, for a conſiderable time; and it was evident from my obſervations that the *ſphincter ani* was, in the firſt inſtance, relaxed by the expulſion of the *fæces*, and the *ſphincter veſicæ* by the expulſion of the urine; but of that power, which produced theſe effects, I was yet ignorant.

Thus doubts, having long exiſted in my mind, led to a diſbelief of this theory, which prompted me to make new enquiries; and at length I had recourſe to experiments. Theſe experiments informed me "That air exiſted in all "matter; that the ſpring, or force of air was in pro- "portion to its weight; that the power of air confined in "a tube, and rareſied by heat, was, by the act of rarefaction, "conſiderably encreaſed—that moſt of the tubes of an "animal body poſſeſſed an elaſtic, or muſcular property; "that the firſt evident ſign of motion produced in fluids, "by heat, was cauſed by the rarefaction of the air con- "tained in them; that from the degree of heat peculiar to "animal life, the air in an animal became ſo much rarefied "as to be continually in motion;—and, ultimately, that "air did actually exiſt, in this rarified and circulating ſtate, "not only in the blood, but in all the other fluids con- "tained within an animal body*."

* Vide the Principles laid down in the Syllabus. Page 22, &c.

Being

BEING in poſſeſſion of theſe experimental proofs, which were publickly exhibited at my Lectures *, I was led to conſider the arguments againſt the external atmoſphere being admitted into the circulation of our fluids; and to me thoſe arguments appeared altogether inconcluſive. I then began to think it not improbable that the action of air might ſupply the place of antagoniſt muſcles, wherever they ſeemed to be wanting, not only in the Heart, but throughout the animal œconomy.

I SHALL conclude the preſent chapter with a few more experiments and obſervations, that may perhaps ſtrengthen this opinion. It is a fact well known that the hearts of ſome animals will continue to beat with a regular and

* THE experiments, on which the principles are founded, were uſually ſhewn before each Lecture: but, as I wiſhed no Gentleman might be abſent at the proofs of the 27th and 28th Principles, thoſe experiments were exhibited on the ſixth night *between the Lecture and Conjectures*; and they were alſo repeated at the next Lecture. It will moſt likely be remembered that I then addreſſed my auditory in the following manner, for the words are taken from my notes: "As ſome perſons have doubted, and others denied, the exiſtence "of air in the circulating fluids of an animal body, and more eſpecially in the blood; I "wiſh the matter of fact to be eſtabliſhed in the preſence of every Gentleman who does "me the honour of conſidering the preſent important ſubject. For this purpoſe the "Operator has procured a blood-veſſel, ſecured by ligatures before it was taken from the "body of the animal, ſo that no communication can have been admitted between the air "contained in the blood, and the atmoſpheric air, except what is natural in a living "ſtate. He has alſo a part of the medullary ſubſtance of the brain to exhibit: when "you, Gentlemen, are ſatisfied with theſe experiments we ſhall begin with our Con-"jectures." I believe all thoſe who ſaw the experiments admitted that the facts were fully proved; and as they are eaſily made, any Gentleman, in the leaſt acquainted with the management of an air-pump, may readily obtain ocular demonſtration of the Truth of the above principles.

forcible motion for ſeveral hours after they are ſeparated from the body; and I thought it applicable to our preſent inquiries, to learn how far the ſpring and force of the atmoſpheric air might be inſtrumental to this motion; for many effects are familiar to us, though their cauſes lie hid.

EXPERIMENT I.

The Heart of a ſmall Eel, ſeparated from its body, beat twenty ſtrokes in a minute, regularly and forcibly; being placed under a receiver, as the air was exhauſting it encreaſed to twenty-four ſtrokes; but the motion was more feeble: in three minutes it was ſcarcely perceptible: by admitting freſh air the motion of the heart returned with equal force as at firſt; and, by exhauſting it again, the motion regularly decreaſed. Freſh air was admitted a ſecond, third, fourth, and fifth time; in each trial the motion of the heart regularly returned; and it was as ſenſibly diminiſhed, on the receiver being exhauſted: at length, the fluids proper to the heart itſelf having in a great meaſure tranſuded, the muſcular fibres became dry, and loſt their power of re-action, when all motion ceaſed.

EXPERIMENT II.

On the Heart of a Tench.

The fiſh was very lively, and weighed near a pound; when the heart was taken out, it beat twenty-two ſtrokes in a minute, regularly and forcibly; I could not obſerve

it

it to beat quicker when put under the receiver; if it did, it was not more than one ſtroke in a minute—but, as the air was exhauſting, the motion became viſibly weaker, and in four minutes it almoſt ceaſed; on the admiſſion of freſh air, the motion returned with full force; and it again ceaſed, or ſcarcely moved, when the receiver was a ſecond time pretty highly exhauſted. The air was admitted again and again, and alſo exhauſted as in the former experiment; and each time the effects were exactly ſimilar.

The heart of the Tench was much larger than that of the Eel, and when the receiver had been ſix times exhauſted the muſcular fibres of this heart ſtill retained their capability of re-action; and, being expoſed to the atmoſpheric air, the heart continued to beat regularly and forcibly for a great length of time.

EXPERIMENT III.

The Heart of a ſmall, but very lively, Eel, when taken from the body, beat ſixty bold and regular ſtrokes in a minute; being put under the receiver, and the air gently exhauſted, its motion became more feeble, and the heart beat only forty ſtrokes in the minute; the ſtrength of its motion gradually abating, and being almoſt imperceptible, the air was re-admitted as in the former experiments, when the heart beat again with full force, but not more than forty ſtrokes in the minute, and the experiment continued as before.

EXPERIMENT IV.

ANOTHER Heart beat only eight ſtrokes in a minute when taken from the body; theſe ſtrokes were bold but irregular: this heart being put under the receiver, and the air gradually exhauſted, the pulſations quickly encreaſed to the number of eighteen in the minute; they were leſs forcible, but more regular; when the receiver was nearly exhauſted, the motion of the heart was ſcarcely perceptible, but on the re-admiſſion of the atmoſpheric air, it returned again with its former force, and the experiment continued as before.

EXPERIMENT V.

THE Heart of another Eel being placed under the receiver, and the air expeditiouſly exhauſted, a very fluttering motion was ſoon diſcernible; when the receiver became highly exhauſted the air proper to the juices of the heart itſelf tranſuded, and remained on its ſurface in tranſparent globules; in a very few minutes the heart ceaſed to beat, it appeared dry and withered, and although the atmoſpheric air was re-admitted no motion returned; for the muſcular fibres had loſt their power of re-action.

EXPERIMENT VI.

THE Heart of an Eel was placed under a receiver, and the air nearly exhauſted; another heart at the ſame time was expoſed to the common air of the atmoſphere: the motion of the heart under the receiver was feeble and quick;

quick; but it entirely ceaſed in fifteen minutes; whereas the heart expoſed to the atmoſpheric air continued a forcible and regular motion for an hour and half; then, gradually declining, it ſtopped in about two hours and an half.

EXPERIMENT VII.

THE Heart of an Eel was placed under the exhauſted receiver, about ſix minutes; till its motion was no longer perceptible; but, being taken out and expoſed to the atmoſpheric air, the motion of this heart inſtantly became ſtrong and regular; and it continued to beat nearly as long as another heart which had not been placed under the receiver *.

FROM the above experiments this general concluſion, I think, may fairly be drawn; that not only the ſtrength of the

* THESE experiments require great attention: the health of the animals, and perhaps the ſize of them ſhould be regarded; the goodneſs of the air pump, the dimenſions of the receiver (that I lately uſed, was $1\frac{3}{4}$ inches in diameter, and $6\frac{1}{2}$ in altitude) whether the receiver be haſtily or ſlowly exhauſted, and how highly. I object to the uſe of oil in this, and every other experiment on animal motion. Care ſhould be taken not to wound the heart; ſometimes I have not divided it from the liver and other inteſtines, but the effect was nearly the ſame. I have frequently taken off its *pericardium*; this, however, muſt be done with a nice hand; I think the motion is then ſlower, but more regular and bold, and the experiment more beautiful.

I MADE many experiments to learn why ſome hearts beat quicker than others when taken from the body, and am not yet thoroughly ſatisfied: it is proper to remark the Eels were ſmall, and perhaps ſome of the hearts might be injured; or, coagulated blood might *more or leſs* obſtruct the admiſſion of the air into all of them: ſome did not beat more than ſix or eight ſtrokes in a minute, others from 10 to 20, and ſo on to 40 and 60; but I do not

the motion of the heart, but alſo the continuation of its motion, ſeems to depend *altogether* upon the weight and ſpring of the atmoſpheric air. In proportion as the receiver became more highly exhauſted, in every experiment, we obſerve the action of the heart to become more feeble: and when the hearts ceaſed, or nearly ceaſed to beat, by introducing freſh air, motion conſtantly and forcibly returned; except in thoſe caſes where the muſcular fibres had loſt their power of re-action.

I SHALL leave the application of theſe experiments to my readers; and if what has been advanced in the preſent chapter ſhould incline learned and philoſophic men to think we are treading on ſolid ground, I hope, from our future inquiries, they may alſo be induced to think with me it is highly probable that the atmoſpheric air is continually received into animal bodies, in order to ſupport that ſtandard peculiar

recollect that any two beat exactly alike. While the air was exhauſting, the motion of ſome of the hearts became ſlower, others did not vary in the number of ſtrokes, others again became quicker—I am equally at a loſs to account for theſe different effects, if they may not be aſcribed to the cauſes before mentioned.

EXPERIMENTS we know will vary, and theſe remarks may prove agreeable to the curious; they may aſſiſt them in farther purſuits; the ſubject is copious, perhaps important: I will thank any Gentleman who ſhall hereafter communicate to me his obſervations. It may not be improper to remark, for the information of ſuch as are not well acquainted with the laws of Pneumatics, that the ſpring and force of the atmoſpheric air is abated by taking away a part, in proportion as it is rendered lighter; it is likewiſe abated by humidity, in proportion as it is rendered humid; yet, when air becomes rarefied and expanded by

peculiar to VITAL AIR; by which power the circulation of our fluids is uniformly maintained: and likewiſe that the ſpring and force of air ſupplies the place of antagoniſt muſcles, not only in the heart but throughout the animal œconomy.

THE doctrine of Vital Air, and the natural means of ſupporting its ſtandard, by the conſtant admiſſion of the atmoſpheric air into animal bodies, may *perhaps* be new; yet, I am by no means ſingular in opinion, that the action of air may ſupply the place of antagoniſt muſcles: tho' many learned men have denied, others have aſcribed this power to the atmoſpheric air; but I believe they have gone no farther: be this as it may, true philoſophy muſt ever be built on experiments; and, without this ſolid baſis, the opinions even of the wiſeſt men ſhould be received with caution: for which reaſon I wiſh not, on the preſent occaſion,

by the power of heat, whether it be dry or humid, if this air be confined in tubes its ſpring and force will be prodigiouſly encreaſed, by the act of rarefaction.

I SHALL make one more obſervation. As we preſume the power and ſpring of air to be the firſt cauſe of motion in the heart of the Eel when taken from the body, how are we to account for the heart's motion continuing, even for a ſhort ſpace of time, under what is termed an exhauſted receiver? I anſwer, in the ſame manner as we account for ſome animals living much longer than others in the above ſituation. Were it practicable, totally to exhauſt the air from a receiver, and in an inſtant of time, I apprehend that all animals would be as quickly deprived of motion and life by this means, as by the act of drowning, or many other modes of ſudden death: but, by the uſe of the air-pump we only take away part of the air, whereby that which remains, *expanding*, becomes ſpecifically lighter, and thereby loſes a certain

caſion, to avail myſelf of the ſanction of any names, however high and reſpectable: my conjectures, ſuch as they are, originate from my own experiments: my errors and miſtakes I lay at no man's door; and if there be any truth in what I advance, I am perſuaded that in the paths of ſcience TRUTH will make its own way.

certain portion of its ſpring and force: hence, thoſe animals that naturally exiſt in a lighter or leſs elaſtic atmoſphere are not ſo quickly deprived of life, by means of the air-pump, as thoſe that uſually breathe the heavier air common to us. Aquatics come under the denomination of thoſe that naturally breathe an humid and leſs elaſtic atmoſphere; the Tench and Eel, therefore, are not eaſily to be deprived of life by means of the air pump: and as we perceive the motion of the heart, when taken from the body, can be ſupported for ſome hours by the weight and ſpring of the atmoſpheric air, can we be at a loſs for a reaſon why it ſhould continue to beat a few minutes under the receiver? It is ſubmitted to the public, how far theſe experiments may be applicable to our inquiries, concerning the importance of the atmoſpheric air in animal life.

END of the FIRST CHAPTER.

PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

CHAPTER THE SECOND.

CONTENTS.

The moſt material objections of Dr. Boerhaave and others, againſt the admiſſion of the atmoſpheric air into the blood by the lungs, examined: farther reaſons aſſigned for rejecting Boerhaave's theory of the circulation of the blood: a deſcription of the heart: a new theory of the circulation propoſed; and the mechanical cauſes attempted to be explained: the contradictory opinions of Dr. Harvey and Dr. Boerhaave in ſome meaſure reconciled.

PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

CHAPTER THE SECOND.

IN the firſt Chapter of our Inquiries we had recourſe to the atmoſpheric air, as the natural means of ſupporting the ſtandard of that VITAL AIR, which we ſuppoſe to be the firſt material cauſe of motion in animal life: it will, therefore, be neceſſary to take a review of the moſt material objections that have been advanced againſt the admiſſion of the atmoſpheric air into the circulation of our fluids; and from this review, perhaps, the candid reader will perceive we have not haſtily formed our own opinions.

THE illuſtrious Borelli was firmly perſuaded, that the heavy and elaſtic air of the atmoſphere was admitted by the lungs into

into the blood, which the learned Boerhaave takes notice of, but denies the fact *. He positively says, "it cannot be "by the arteries; nor, *does it appear from any argument to* "*be*, by the veins." We readily grant the former part of this assertion, that the atmospheric air cannot be admitted by the arteries, on account of the resistance it would there meet with from the blood moving in a contrary direction; and Boerhaave himself does not assert, *it cannot be admitted by the veins*; he only says, it does not appear from any argument. We allow no arguments had been urged, at that time, sufficient to induce him to believe the atmospheric air was admitted into the blood, by the pulmonary veins; yet, from this peculiar mode of expression, it is apparent Boerhaave was far from thinking it impossible; for, his very words seem to leave the matter of fact open to future inquiry; and we hope to be able, *by many arguments*, to set forth the moral certainty of it; which is, perhaps, the highest degree of evidence we shall ever arrive at concerning the laws of respiration.

Let us then examine the objections advanced by Dr. Boerhaave against the admission of the atmospheric air into

* An autem partes graves, et elasticæ, aëris hîc miscentur sanguini pro vitali elasticâ oscillatione, ut docet eximius Borellus? id nequit fieri in arteriis, nec ullo argumento constat in venis. Quin creditur obesse aër vesicas extendendo venas comprimens in inspiratione; vis comprimens thoracis venas arctans in expiratione; singularis hîc arteriæ in venam commutatio; difficilis aëris transitus in meatus parvos, aquæ pervios, oleo, et spiritibus; humor lubricus membranæ succingentis interiora trachææ; aëris sanguini infusi noxia.

Boerh. Inst. 201.

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the blood by the pulmonary veins: he obſerves that this air, by extending the veſicles of the bronchia, compreſſes the veins in inſpiration; and he ſays, the compreſſing force of the thorax narrows the veins in expiration; both theſe aſſertions, however, appear to me to be improbable. It is a well known fact, that not only air but all other fluids put in motion will take that direction where they meet with the leaſt reſiſtance; hence the veſicles of the bronchia readily yield to the propelling force of air in inſpiration: and it appears to me to follow, that the veins, diſtended with blood, reſiſt the compreſſing force of theſe inflated veſicles; for the power of any given quantity of air is abated, in proportion as it is divided, and ſubdivided, into parts that are kept aſunder from each other; and the innumerable cells of the bronchia ſeem admirably contrived by the Author of Nature to prevent this very compreſſion contended for by Dr. Boerhaave. Nor, in expiration can we ſuppoſe the channels of the pulmonary veins to be narrowed by the compreſſing force of the thorax, becauſe the veſicles of the bronchia as readily yield to this power; and as the air received into them by the act of inſpiration is at this time diſcharged, the veſicles themſelves muſt occupy leſs ſpace: where then is the neceſſity of the pulmonary veins being narrowed in expiration by the compreſſing force of the muſcles of the thorax? We cannot indeed conceive it to be natural, either in inſpiration or expiration, that any conſiderable compreſſion ſhould take

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place in the pulmonary veins, as it would be an impediment to the circulation of the blood itſelf, which reſpiration is intended to promote.

From the foregoing obſervations, one point, at leaſt, ſeems clear; that as the atmoſpheric air is diſcharged from the veſicles of the bronchia in the act of expiration, if it be admitted from the veſicles into the blood at all, it muſt enter the veins during that period; and this is a circumſtance particularly to be remembered, when we ſpeak of the laws of reſpiration.

In the next place Boerhaave takes notice of the ſingular changing of the artery into a vein in the lungs. A very laconic mode of expreſſion; but to have ſaid more might perhaps have made altogether againſt his opinion: for a ſingularity takes place in the bronchial arteries and veins, (which are appropriated to the nouriſhment of the lungs,) by their frequent *anaſtomoſes* not only with each other, but particularly thoſe of the bronchial artery with the pulmonary vein: do not theſe *anaſtomoſes* evidently ſhew that ſomething more than nutrition was provided for in theſe important organs of reſpiration? — Another obſervation occurs in this place, namely, that the ramifications of the pulmonary artery are more numerous and larger than thoſe of the pulmonary veins; this indeed is ſingular, as in all other parts of the body the veins exceed the arteries both in

in number and ſize; and this ſingularity, likewiſe, will hereafter command our attention.

Boerhaave farther urges the difficult tranſit of air into narrow paſſages, (by which I preſume he means pores) pervious to water, oil, and ſpirits. The matter of fact in this inſtance is againſt him; for it is well known to thoſe who have made experiments on air, that under certain circumſtances air will paſs through cavities impervious to ſuch fluids; and here we muſt beg leave to obſerve alſo that there is a cellular membrane proper to the lungs, and in contact with the veſicles of the bronchia: all the bronchial cells, Malpighi particularly remarks, are ſurrounded by a very fine reticular texture, of the ſmall extremities of the pulmonary arteries and veins, which communicate every way with each other; and M. Helvetius aſſerts, that by blowing into this membranous ſubſtance, the air thus admitted will compreſs the lobes of the lungs; and he farther ſays, which more particularly makes for our purpoſe, that by blowing forcibly into the bronchial veſſels, the air paſſeth inſenſibly into this interlobular ſubſtance. Thus it appears by the experiments of this very accurate obſerver, that there is a paſſage which admits air to the extremities of the pulmonary arteries and veins: this alſo deſerves particular notice.

Boerhaave adds another impediment, which is, the lubricating humour of the membrane that lines the trachea; he might have carried this objection farther, as we will allow the like humour to exiſt through all the veſicles of the bronchia; it is a glandular ſecretion, proper to tubulous parts and membranous ſurfaces; and we will venture to ſay, it is a mucus, ſecreted by the power of vital air, evidently intended to prevent injurious friction on all occaſions, and, in the preſent inſtance, to defend the parts againſt the force of the atmoſpheric air, in its tranſit through the trachea, and the bronchial veſicles, into the pulmonary veins. Malpighi's experiment of injecting ink into the pulmonary artery, and thereby tinging this lubricating humour that lines the trachea, alſo proves that there are channels of communication between the arterial tubes and the trachea: when therefore we take into conſideration theſe experiments of Helvetius and Malpighi, although we may not allow them to be proofs altogether ſatisfactory, we muſt acknowledge they are ſtrong preſumptions in favour of the paſſages contended for.

In the laſt place Boerhaave aſſerts the noxious effects of air infuſed into the blood. This likewiſe is a very laconic expreſſion. Improperly admitted, we grant its full force; becauſe the power of air may deſtroy animal life; but the ſtructure of the lungs, and particularly of the bronchial cells, is ſo admirably contrived by the Author of Nature

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as ſufficiently to guard againſt this injury, in an atmoſphere friendly to animal life; and it is well known, by excluding the common air of the atmoſphere from an animal, that death ſoon enſues.

It does not appear that Boerhaave intended to make a diſtinction, in this laſt objection, between a pure and an impure atmoſphere; and, indeed, if the air only acts upon the blood in the lungs, by its weight and preſſure without mixing with it, the purity or impurity of the air we breathe, ſhould ſeem to be a matter of indifference, provided its ſpecific gravity was not materially altered. In juſtice, however, to the memory of ſo illuſtrious a character, it is proper to mention that many important diſcoveries, familiar to us, concerning the properties of air, and its various combinations with other particles of matter, were altogether unknown to Boerhaave. But, at this time, even from experience, we may, with ſome degree of propriety, ſpeak of the noxious effects of impure air infuſed into the blood, and circulating in the animal œconomy.

In one of my lectures on diſeaſes, I had occaſion to dwell much on this point. In the ſmall-pox, for inſtance, both in the natural way, and by inoculation, I endeavoured to ſhew that the unfriendly ſtimulus producing the diſeaſe muſt neceſſarily float in air; that in the natural way it is chiefly received by the lungs—but in inoculation by the excretory

glands of the ſkin: and I endeavoured to account for the ſecretion of the variolous matter from the ſtimulating property of this noxious air.

It is, likewiſe, well known not only to medical practitioners, but to moſt men, that the putrid effluvia of a ſick chamber may, and too often do prove fatal to thoſe, who are either compelled by duty, or induced through humanity, to breathe in ſo impure an atmoſphere. If this be allowed, can we doubt the rational probability of the admiſſion of the atmoſpheric air into the blood, in its circulation through the lungs? It would be tedious to enumerate all the objections which, from miſtakes and prejudices, have been advanced againſt the admiſſion of the atmoſpheric air to the heart, by means of the lungs; out of reſpect, however, to the eſtabliſhed reputation of Dr. Needham we ſhall take notice of a few more difficulties ſet forth in his treatiſe *De Formato Fœtu*.

For his firſt objection he quotes high and learned authorities, "that the pulſation of the heart does not exactly "correſpond with reſpiration *;" and this I believe has hitherto been regarded by many as an inſurmountable difficulty. We readily admit the fact; it is well known, in

* Certe magni momenti eſt illud *Highmoro-Boylianum*, nempe quod pulſus reſpirationi non accuratè reſpondet—adeò ut, ſive ſyſtole, ſive diaſtole recipiatur, neutra inſpirationi ſynchronica eſt, ſed aliam prorſus motuum ſuorum proportionem obſervant.

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the action of diving, for inſtance, and by other experiments, that the circulation may uninterruptedly continue for many ſeconds, including at leaſt an equal number of pulſations, although reſpiration be ſuſpended: nor is it neceſſary, according to our theory, for pulſation to be *ſynchronous*, or exactly correſpondent in time with reſpiration; for we do not conſider reſpiration as the firſt cauſe of pulſation, though it be eſſentially neceſſary to its continuance after the birth of an animal; and had not the Author of Nature been thus provident, our corporeal tenement would be more brittle than it is.

This objection, therefore, does not, in the leaſt, affect our principles—it is by the power of Vital Air that we preſume the circulation of the blood is regularly and uniformly maintained; and we regard the lungs of an animal only as one order of excretory glands, by which a juſt and adequate portion of the cooler and heavier air of the atmoſphere is conſtantly received into the blood, and the lighter air of the body as regularly diſcharged; for we mean to contend that a ſimilar operation takes place by the excretory glands of the ſkin; and there are alſo other channels by which an heavier air is occaſionally introduced into the circulating fluids, which we ſhall ſpeak of in the proper place.

Thus we ſhall endeavour to make it appear that animal bodies are amply provided with the means by which a cooler

and

and heavier air than that exiſting in them is continually admitted, in order to ſupport the ſpring and power peculiar to Vital Air; and thereby to maintain that proper ſtandard neceſſary to life itſelf, not only in the human ſpecies, but throughout the whole animal creation: for the ſpring and power of Vital Air we preſume to be different, in different animals: hence, we may rationally account for the degrees of heat proper to animal life, in the various orders of animated beings; and alſo for their exiſting, ſome in warmer or dryer, others in colder, or more humid atmoſpheres; yet all according to the general law of our omniſcient Creator; and this law appears to us to be that of the atmoſpheric air, proper to each diſtinct order of animated beings, being ſomewhat colder, and heavier than their own vital air. Theſe remarks may perhaps be pleaſing to thoſe acquainted with the uſe of the air-pump, and to enlarge farther on this point would be foreign to our preſent deſign, and altogether ſuperfluous; for beginning with the lower orders of animated beings, proceeding experimentally and gradually aſcending to the moſt animated, the rule ſeems to be univerſal *.

Dr. Needham alſo obſerves, "the atmoſpheric air "cannot be admitted to the heart by means of the lungs, "in many animals, becauſe they have no lungs." We certainly ſhall not attempt to prove air may paſs through the

* For farther information on this ſubject, vide note, p. 27 & 28. chap. 1.

lungs

lungs of animals that have none, and readily grant the Doctor every thing he could wish in this argument—*except the conclusion:* for it is universally allowed that the animals alluded to have vesicles for the reception of the atmospheric air, through which it may be transmitted to the circulating fluids. Whether such cells be termed lungs or not, or in whatever part of the body they may be placed, is to us altogether a matter of indifference: so that a communication between the atmospheric and vital air be constantly maintained, 'tis all we ask; and without this communication *we can prove* animal life cannot be supported. This objection, therefore, appears to be nothing more than a scholastic quibble; and what has been advanced will perhaps be received as a direct answer to his observations concerning birds; since experiments on the air-pump sufficiently convince us, that the plumed race are equally dependent upon a constant supply of atmospheric air for their existence, with every other animated being.

The whole of Dr. Needham's difficulties respecting fishes are easily and readily to be solved, by attending to the explanation of our 13th principle; which shews motion and heat to be relatively dependent on each other: we shall not, therefore, enter into his detail, since it is well known that the inhabitants of the waters require a change of air in common with other animals, although they are capable of existing in a less elastic atmosphere than that we breathe; less

elaſtic, on account of the air being rendered more humid by the water. But when water is put into briſk motion the air becomes more elaſtic, and we then obſerve diſtinct globules of air, and that each globule is incloſed within its proper tunic formed of the water, in like manner as when heat is applied; and we may farther take notice, that when the bubble burſts, this elaſtic air eſcapes: when, therefore, we conſider the formation of the mouth and the gills of fiſhes, and their uſes, can we be at a loſs to imagine how the generality of fiſhes are conſtantly ſupplied with a colder and heavier air than that exiſting in their own bodies?—and we may reſt aſſured that the Author of Nature has not neglected thoſe which poſſeſs little or no loco-motive power, ſince he has ſo wonderfully diſplayed his wiſdom in thus providing for the ſuperior inhabitants of the watry region.

HAVING thus anſwered every objection of the learned Dr. Needham, which appears to make againſt our opinions, we ſhall obſerve, that from many experiments exhibited in ſupport of our principles, other arguments may be drawn in favour of the admiſſion of the atmoſpheric air into the circulation of our fluids; and, when we come to ſpeak of the laws of reſpiration, we have yet farther proofs in reſerve, that more immediately appertain to the mechanical conſtruction of the lungs themſelves.

LET us now return to the immortal Harvey, who, reaſoning on the motion of the blood, takes particular notice that the beating veſicle, as alſo the auricle of the heart when completely formed, whence pulſation begins, is irritated to the motion of contraction by the diſtending of the blood *: and ſpeaking of the cauſe of its diſtenſion, he ſays the diaſtole is made by the blood ſwelling up, as if by an internal ſpirit †: from whence he draws this concluſion, that the opinion of Ariſtotle concerning the pulſation of the heart, happening after the manner of ebullition, is in ſome meaſure true ‡: and my great oracle farther adds, "that which we daily behold in milk heated by fire, "and in the fermentation of beer, the ſame happens in the "pulſation of the heart §." In confirmation of this aſſertion of the illuſtrious Harvey, we have fully proved, by experiments ‖, that theſe effects are produced by the power of the air contained in thoſe fluids.

* Certumque eſt veſiculam dictam, ut et cordis auriculam poſtea, unde pulſatio primum incipit, a diſtendente ſanguine ad conſtrictionis motum irritari.

† Fit, inquam, diaſtole a ſanguine ab interno quaſi ſpiritu intumeſcente.

‡ Adeoque Ariſtotelis ſententia de pulſatione cordis (fieri eam, *ſcilicet*, ad modum ebullitionis) aliquatenus vera eſt.

§ Quod enim in lacte ab igne calefacto et cerviſiæ noſtræ fermentatione quotidie cernimus, idem etiam in pulſu cordis uſu venit.

‖ Vide Principle 14, &c.

THIS

THIS leads me to take notice of one more objection againſt the admiſſion of the atmoſpheric air into the circulation of our fluids, on which the followers of Boerhaave, who place their faith in animal ſpirits, ſeem greatly to depend: namely, that the air within us is always in equilibrium with the air without us; and conſequently, they ſay, the preſſure of the atmoſphere can neither promote, nor retard, the contraction of the thorax, nor the dilatation of the heart; and thoſe bewitching ſpirits would not ſuffer them to conſider the poſſibility of the atmoſpheric air reaching the heart, by means of the lungs; nor the encreaſed power of that air, rarefied by heat, and, in a circulating current, confined within tubes.

THAT there muſt be a juſt balance continually preſerved between the atmoſpheric air, and that circulating in an animal body, in order to preſerve life, I could readily aſſent to: but as the technical term equilibrium is derived from the Latin *æquus*, equal, and *libra*, weight; if the expreſſion be thus uſed, to ſhew, that a given quantity of air within an animal is equal ſpecifically in weight to the ſame quantity of atmoſpheric air, the argument is altogether fallacious. The contrary has ſufficiently been proved by experiments; and the matter of fact is at this time, I believe, well known to philoſophic men.

THE

The numerous proofs exhibited in ſupport of our principles fully authoriſed me to explode this idea; and when we reflect on the encreaſed power of air, rarefied by animal heat, and circulating in the vaſcular ſyſtem, and take into conſideration the external coverings of animal bodies—can we be at a loſs to preſerve the equilibrium neceſſary to life, between vital air, and the ſurrounding atmoſphere?——No more, than to balance any given weight, by regulating the powers of the ſteel-yard; or to account for the mechanical operation of the fire-engine: hence, reaſon and reflection founded on experiments, in my mind, at leaſt, quieted thoſe perturbed ſpirits, and conſigned them peaceably to the tomb of oblivion.

The magic ſpell thus broken, I found myſelf at liberty not only to purſue the operations of reſpiration, and the circulation of the blood, but to follow the digeſtive faculties, the reception of the chyle into the blood, and the numerous glandular ſecretions for the purpoſe of nutrition, together with the diſcharges of excrementitious particles of matter from the animal œconomy: throughout the whole of theſe reſearches, I had the ſatisfaction to find that air, the firſt cauſe of motion in animal life, continued to act in the production of all the various effects, neceſſary to the maintenance and ſupport of life itſelf. I could not then but yield my rational aſſent to the truth of this theory; which led me, with profound reverence, to contemplate the

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wiſdom of the Author of Nature; and, admiring the ſimplicity of the means made uſe of in all the wonderful operations of an animal body, to attempt to prove, by experimental philoſophy, that air is the primary agent in animal life.

The arguments already uſed, to obviate the moſt material objections againſt the admiſſion of the atmoſpheric air into the circulating fluids of an animal, may perhaps induce ſome to think with us it is highly probable that this air is received into animal bodies; yet, we wiſh ſuch readers not to fall in with the preſent opinions too haſtily, and caution others againſt condemning them too raſhly; and that no one may inadvertently be miſled, we ſhall make a few remarks upon the whole that has been advanced.

Although we have ſhewn air does actually exiſt in the blood, and likewiſe in the medullary ſubſtance of the brain, thoſe experiments were not intended to prove any thing farther; they cannot convince us that this air was in an active ſtate in the living body. The ſame thing is to be obſerved with regard to the experiments on the hearts of ſome animals when ſeparated from the body; for if the ſpring and weight of the atmoſpheric air, as we believe, is the firſt cauſe of the regular and forcible motion of the heart in this detached ſtate, we are not authoriſed to conclude, from thence, that air is the firſt cauſe of animal motion.

motion. We wiſh it, therefore, to be fully underſtood, it is not any experiment, *ſingly*, nor any number of ſuch experiments, however they may appear to ſtrengthen our opinions, on which we mean to build our new doctrine concerning the circulation of the blood.

To comprehend the full force of our arguments, the reader muſt condeſcend to examine the chain of principles ſet forth in the Syllabus, together with their experimental proofs; otherwiſe he cannot, however learned, enter with us philoſophically into this ſubject. One great object of the courſe of Lectures was to endeavour to inveſtigate the ſimple elements of Pneumatics, ſo far at leaſt as they might be ſuppoſed to appertain to the laws of animal life. We began firſt with conſidering air as matter, and ſecondly as a fluid; we then pointed out its peculiar properties, and ſet forth how it differs from other fluids: we afterwards proved air to exiſt in all bodies, both fluid and ſolid; and after ſhewing its various combinations with other particles of matter, we proceeded to explain and confirm, by experiments, the effects of heat and motion on the air exiſting in different fluids; till, at length, by a regular connection of ſimple elements we arrived at a moral certainty, from the degree of heat and motion proper to animal life, that the air exiſting in animal fluids muſt be in a rarefied and active ſtate. We then ſhewed that air, in this rarefied and active ſtate, was capable of producing a circulation in a fluid confined

confined in a tube, without the aid of re-action of the tube itſelf—from whence this concluſion ſeems fairly to be drawn, that VITAL AIR is endowed with power ſufficient to produce a circulating motion in the fluids contained within an animal body. On this baſis our definition is eſtabliſhed. "Air "rarefied, in motion, detained in animal bodies by glan- "dular ſecretions, or circulating with the fluids in the vaſ- "cular ſyſtem, permit us to call VITAL AIR *."

ON this foundation our doctrine is built; and from the truth of it all our arguments derive their importance. Other collateral proofs have and will occaſionally be advanced in ſupport of our general principles; as ſuch we conſider the experiments on the blood veſſel and ſome others—for many men have denied the exiſtence of air in the blood of an animal; it was, therefore, incumbent on us to eſtabliſh the fact: but we depend on our principles to prove the activity and power of this air in the living body; and ſo long as our ſimple elements remain unimpeached, this very important point muſt neceſſarily be admitted.

IN all ſubjects not ſtrictly mathematical, it is allowed, the higheſt degree of proof we can aim at is that of rational probability; for inſtance, in natural philoſophy, it will be granted that ſimilar cauſes produce ſimilar effects: by this

* Principle 33.

rule,

rule then, let us examine the preſent doctrine. We have proved by a chain of experiments, *that air does exiſt in animal fluids*; *that this air is neceſſarily in a rarefied and active ſtate, and capable of giving motion to fluids that are confined within tubes.* What inference is to be drawn from hence?—As we know by experience that a part of the fluids is continually paſſing off from animal bodies, and conſequently a portion of this rarefied air along with them, it is evident that animal life requires a ſupply of air. This will readily be admitted: but, perhaps, it may be urged that this ſupply is derived from our daily aliments. We know that a certain portion of air, ſufficient to propel the chyle through the chyliferous veſſels into the blood, is received by means of our nutriment, as we ſhall explain when we come to ſpeak of the laws of digeſtion and nutrition: but if it be ſaid that the chyliferous veſſels are the only channels through which an heavier air than that exiſting in animal bodies is received—how is this ſupply to be derived in times of long faſting?

Besides, we know that air is rendered lighter by taking away a part, and of courſe weaker; hence, if animals did not receive a *conſtant* ſupply of heavier air, in proportion to the continual waſte of vital air, the regular circulation of fluids could not long be ſupported.—This argument ſhews the neceſſity of air being continually admitted into the blood. We alſo know that muſcular motion, the cir-

culation of the fluids, and life may continue, for ſome days, without meat or drink; but not many minutes, if the common air of the atmoſphere be excluded from an animal.—Can this neceſſary ſupply of air, then, be effected ſo regularly and uniformly, by any other means, as by the conſtant admiſſion of the atmoſpheric air into the blood?—And as we have farther ſeen that a change of the common air of the atmoſphere, as well as its being cooler and heavier than vital air, is neceſſary to the continuance of life—is it not highly probable that a change of air naturally takes place within the body, to ſupport the ſpring and power of VITAL AIR?—From our ſimple elements, therefore, independent of other experiments, are we not authoriſed to hope and believe we have arrived at a moral certainty, that the cooler and heavier air of the atmoſphere is continually received into animal bodies, to produce this neceſſary change of air, and thereby to preſerve that ſtandard peculiar to VITAL AIR?

IF then the atmoſpheric air be admitted, it will, perhaps, no longer be diſputed that the lungs are among the number of channels by which it is likely to enter into the blood. This is all we need contend for at preſent, for we ſhall endeavour to ſupport our conjectures, as to the manner in which the cooler and heavier air is received into animal bodies,

bodies, and the lighter air diſcharged, in order to ſupport the ſtandard of VITAL AIR, when we come to ſpeak of the laws of reſpiration.

HAVING thus endeavoured to combat the Boerhaavean theory of the circulation of the blood, which, however ingenious, was by no means ſatisfactory to me; I ſhall not farther trouble my reader with the opinions of other men, but endeavour to convey my own thoughts on this important ſubject, with clearneſs and preciſion: but, before we ſpeak concerning the circulation of the blood, it will be proper for the information of ſome readers, not profeſſional men, and not already informed, to enter a little into the branch of anatomy, ſo as to give a deſcriptive view of the form, and mechanical conſtruction of that muſcle called the heart, which we have ſtyled the centre of motion in animal life; this neceſſity will be received as an apology to them, for the uſe of ſome technical terms generally applied on this occaſion; we mean, however, to deſcribe the heart only ſo far as to convey a clear idea of it, conſidered as a mechanical agent in the animal œconomy. It will be unneceſſary to enter into the component parts of this muſcle, it being ſufficient for our purpoſe to underſtand it poſſeſſes all the properties of a muſcle; which, together with its peculiar ſtructure and ſituation, enable it to perform its ſtated functions.

THE

The heart is placed in the middle of the thorax, between the two lobes of the lungs; it is incloſed within the pericardium, which may be conſidered as its tunic, or outward coat; a thin limpid fluid, ſeparated by certain glands, is found within this tunic; the uſe of this fluid, as allowed by anatomiſts, is, to prevent injuries that otherwiſe might ariſe from friction, in the action of the heart itſelf.

The form of the heart approaches to that of an inverted cone, its apex, or point, being at the bottom, and its baſis at the upper end; it is rather inclined to the left-ſide, whereby the right auricle is placed a little lower than the left; this inclination is rationally accounted for, viz. to facilitate the circulation of the blood throughout the animal œconomy.

The heart of an animal may properly be deſcribed as the turning point of a reflex tube, the blood entering in at the right auricle, from the two vena cava's, and paſſing out at the left ventricle into the aorta: and, having already premiſed that the blood muſt neceſſarily be brought to the heart, before it can be diſcharged, we ſhall follow other authors in deſcribing the courſe of the circulation.

The vena cava aſcendens, and deſcendens, which bring the returning blood to the heart, unite in the right auricle, where

where they empty themſelves, and the blood, by the ordinary courſe of the circulation, runs into the right ventricle; at the mouth of which there is a proper valve, to prevent its return into the auricle; from the right ventricle, it proceeds to the pulmonary artery, at the entrance of which there is another valve, aptly contrived, to prevent its return: the blood is now diſtributed throughout the lungs, by means of the branches of the pulmonary artery, and it is conveyed again *immediately* to the heart, by the branches of the pulmonary veins: theſe veins enter at the left auricle, from whence the blood is conveyed into the left ventricle, and by a proper valve prevented from returning; from the left ventricle it is again puſhed forward into the aorta, or great artery, to perform a new circulation throughout the arterial and venal ſyſtem; at the entrance of the aorta there is alſo another proper ſtop to prevent the return of the blood into the left ventricle.

I HAVE endeavoured to deſcribe this compound mechanical agent in terms the moſt ſimple; if, however, a clear idea be conveyed of the conſtruction of the heart, to thoſe who have not made anatomy their ſtudy, my intention is fully anſwered.

ON this occaſion it is obvious to remark the importance of the lungs in the animal œconomy; we perceive that the blood every time it is returned to the heart, is directly diſ-

perſed throughout the lungs, and *immediately* reconveyed to the heart, before it is permitted to begin a new circulation: I may add, before it is capable of performing a new circulation: for had there been no real neceſſity, we may boldly aſſert, this operation of its paſſing through the lungs would never have taken place.

The world are indebted to anatomical reſearches for the diſcovery of this very peculiar circumſtance attending the circulation of the blood; and the matter of fact is all we have occaſion to inſiſt upon.

In the ſtudy of Nature, throughout all her works, however complex the machine, the ſimplicity of the mechanical powers claims the firſt attention of a ſpeculative mind; this obſervation is beautifully illuſtrated on the preſent occaſion; and I believe it will be admitted by every one that the blood, after having performed one round throughout the animal œconomy, undergoes ſome new and important change, in its tranſit through the lungs, eſſentially requiſite to ſupport a ſecond circulation.

What this important change is, has been the ſubject of this enquiry, and were it neceſſary to prejudice the reader by the opinions of other men, I could here quote ſome very reſpectable authorities, beſides the great Borelli already mentioned, that have ſuppoſed it probable, at leaſt, for a part of the air, received into the veſicles of the bronchia,

chia, to mix and unite with the blood; but opinions, however reſpectable, unſupported by facts, are not to be admitted; the preſent doctrine muſt ſtand or fall by the balance of probability, founded on the experimental proofs which we have advanced.

A New Theory of the Circulation of the Blood.

We regard vital Air as the firſt material cauſe of motion in animal life.

We preſume the proper ſtandard of vital air was fixed, by the Author of Nature, at the time of the creation.

From experimental philoſophy it appears highly probable, that the atmoſpheric air is the natural means of ſupporting the ſtandard of vital air, not only in man, but in all other animals.

The heart we have conſidered as the centre of motion in animal life.

It is allowed, that the atmoſpheric air is received into the veſicles of the bronchia, in the act of inſpiration: and, as the lighter air is diſcharged from the body, together with other excrementitious fluids, by expiration; we preſume the atmoſpheric air, at this time, preſſeth into the pulmonary veins

veins; and, incorporating with the venal blood, accompanies it in its return to the left auricle of the heart.

THE lungs, then, we regard as one of the channels appointed by our Creator for admitting the atmoſpheric air, to ſupport the ſpring and power of vital air *.

NOT only the heart itſelf, but the arterial tubes are compoſed of muſcular fibres; and it is admitted univerſally, that a muſcular ſubſtance poſſeſſeth the power of contraction. We preſume, therefore, the re-action of the tubes is the ſecondary † cauſe of motion in animal life, aſſiſting the propelling force of vital air to produce that complete motion termed pulſation, by which the blood is propelled through the heart and through the whole of the arterial ſyſtem; and, if there be no re-action in the venal tubes, the blood is returned through them to the heart again by the power of VITAL AIR.

BUT, the Author of Nature has moſt providentially guarded animal life, by cauſing an operation, nearly ſimilar to that carried on by the lungs, to take place by means of the excretory glands of the ſkin. Here too, a certain

* When we come mechanically to conſider the laws of reſpiration, we hope to be able to explain how the atmoſpheric air preſſeth into the pulmonary veins.

† THE re-action of the vaſcular ſyſtem appears to be dependent on the nerves, but in our lectures we endeavoured to ſhew, that the nerves themſelves were primarily indebted to vital air for their power.

portion

portion of vital air is continually paſſing off, together with other excrementitious fluids; and the heavier air of the atmoſphere as conſtantly preſſeth into animal bodies through the ſame channels, to ſupply the place of what is thus diſcharged, and to give an additional force to vital air, in order to reconduct the blood regularly and uniformly to the centre of motion.

How admirably *ſimple* are the means by which this firſt grand operation in animal life appears to be performed!—And the familiar inſtances that may be called to mind, in the uſe of mechanical * Powers obtained by human invention, ſupport the probability of our mode of reaſoning: if, then, we may dare to mention the wiſdom of Omnipotence, in the formation of man and other animals, we have reaſon to think the Author of Nature has diſpoſed and arranged the particles of matter, ſo that throughout life the ſame firſt material cauſe of motion, Vital Air, ſhould *invariably* produce the ſame effect; and alſo that its ſpring and power ſhould as conſtantly be maintained by the common air of the atmoſphere.

The little ſparrow on the houſe-top, has a natural common right to the atmoſpheric air, equally with the great

* The pump, ventilator, fire-engine, pulſe-glaſs, &c. &c.—By the pulſe-glaſs it is clearly proved that air, rarefied by heat, is capable of giving motion to fluids confined in tubes.

Lord that inhabits the ſtately manſion: place this ſmall bird under a receiver, and exhauſt the atmoſpheric air, then vital air will ſoon loſe its ſpring and power, the blood will ceaſe to circulate, and death follows—Exclude the external atmoſphere, and thereby cut off the common tenure of life from man, and like the diminutive ſparrow, he too muſt fall to the ground.

It is with peculiar ſatisfaction, I am now enabled to ſpeak to the oppoſite opinions of two ſuch great men as Harvey and Boerhaave. The proofs produced by both are admitted, diſcarding only their imaginary agents, as we have ſhewn *experimentally* that vital air is the firſt cauſe of animal motion. We allow a propelling power exiſting in the blood, and alſo the power of re-action of the arterial tubes: and have endeavoured to prove that both theſe powers contribute to the circulation: by thus uniting *their* opinions we have formed our own theory; and, perhaps, reconciled their ſeeming contradictions.

We want no imaginary agents in the blood itſelf; no animal ſpirits, nor antagoniſt muſcles, for the heart or the arteries; we may plainly perceive, the heavier air of the atmoſphere is momentarily admitted to maintain the ſtandard of vital air, which gives motion to the blood, and produces that ſwell in the heart, *diſcovered by Dr. Harvey*, termed its diaſtole; and, likewiſe, that the re-action of the muſcular fibres

fibres cauſeth the contraction *ingeniouſly accounted for by Dr. Boerhaave*, called its ſyſtole; which, together make up that complete motion termed pulſation, the object of our preſent inquiry:—but, hence-forth, if our principles be received, let this mechanical operation be known by the more familiar, yet not leſs expreſſive terms of ACTION and RE-ACTION.

END of the SECOND CHAPTER.